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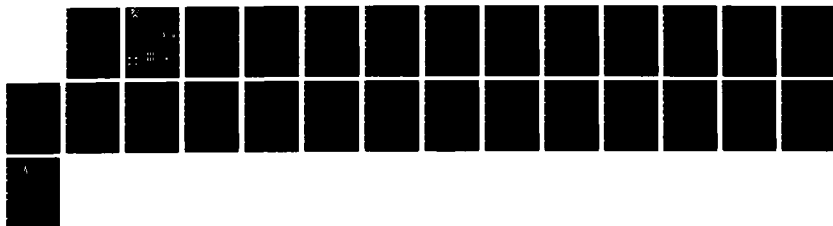
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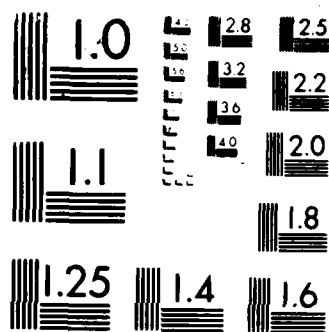
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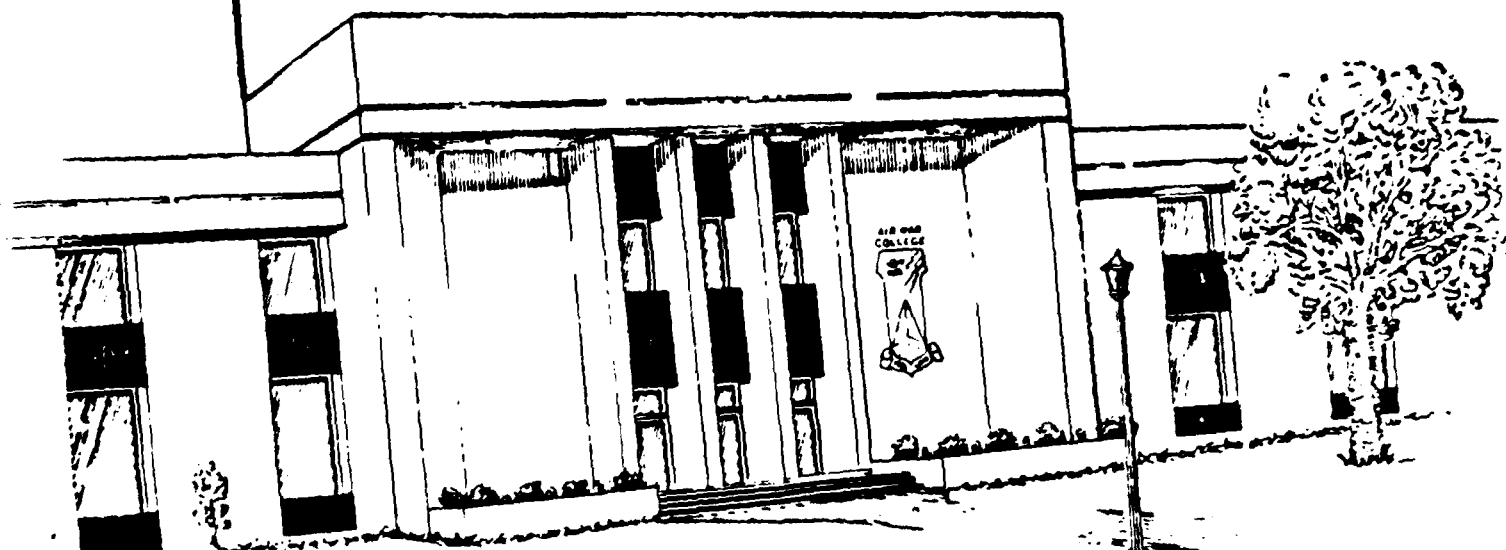
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THE IMPACT OF TECHNOLOGY
ON
FLIGHT SIMULATION

By COLONEL ANTHONY J. TOLIN

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The Impact of Technology
on
Flight Simulation

by
Anthony J. Tolin
Colonel, USAF

A RESEARCH REPORT SUBMITTED TO THE FACULTY
IN
FULFILLMENT OF THE RESEARCH
REQUIREMENT

RESEARCH ADVISOR: Colonel Cecil C. Robins

MAXWELL AIR FORCE BASE, ALABAMA

MAY 1986

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AIR WAR COLLEGE RESEARCH REPORT ABSTRACT

TITLE: The Impact of Technology on
Flight Simulation

AUTHOR: Anthony J. Tolin, Colonel, USAF

Remarks on the debate of flying time versus simulator time introduce a discussion on the impact of technology in flight simulation. A brief look at the history of flight simulators is followed by a more detailed analysis of where the Air Force is today with regard to flight simulation. This analysis looks at the advantages of simulators, the choice between motion and visual systems, and addresses several problems and issues. After a discussion of the future in flight simulation, the conclusion that simulation is here to stay as a complement, not a replacement for, actual flying hours is developed.

BIOGRAPHICAL SKETCH

Colonel Anthony J. Tolin (M.A., LaVerne University) is a command pilot with nearly ten years and 2500 hours involved directly in the training of new pilots and new fighter pilots. He has instructed in numerous simulators over his 19 years in the USAF. Additionally, he participated in the OT&E of the Simulator for Air-to-Air Combat (SAAC) at Luke AFB, Arizona. He is a graduate of Squadron Officers School, Air Command and Staff College, and the Air War College, class of 1986.

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CHAPTER I

INTRODUCTION

Websters defines a simulator as "a device or apparatus that generates conditions approximating actual performance or operational conditions." The USAF dictionary further defines many different types of simulators and training devices to include: part task trainer; cockpit procedures trainer; operational flight trainer; and weapons system trainer. For the purposes of this paper, I will use the generic term "flight simulator" to refer to those devices which both simulate flight and are designed to provide an environment in which aircrews learn, develop, and improve the techniques associated with their crew position in a specific aircraft.

The simulation of aircraft characteristics has been going on for more than 50 years. During those years it seemed logical to speculate that someday the simulators might become so sophisticated that the use of the airplane for training might become unnecessary. Parallel with this apparent logical thought process has been the much-debated question of the actual relation between flying the aircraft and "flying" the simulator. The real question boils down to, Can simulator time replace flying time?

One school of thought insists that the dramatic growth in flight simulation technology has made zero aircraft time for training a reality under some circumstances.(1:49) The other school of thought is emphatic that any simulation time must be in addition to flight training. To an extreme, this

group contends that replacement of flying time with simulator time "... moves us toward the position where our wartime mission capability will approximate our peacetime flying program and you can't kill the enemy with a simulator."(2:10)

The official Air Force position is that flight simulators are needed and they should complement the flying training program. The Air Force has successfully used different levels of flight simulation over the years. The training associated has been broken down into two distinct types. The first is safety-of-flight training which consists of procedures training and coordination. The second is warfighting training for those combat tasks that can be trained effectively in a simulator. The second type adds directly to combat readiness.

Proponents of more simulator time and less flying time continually refer to the rapidly escalating costs associated with the purchase and operation of military aircraft. At the same time they point to the relatively cheap "flying hours" in a simulator.

This paper will first take a discuss the history of simulation. Next will be a discussion of where we are today, the advantages/disadvantages of simulation, and problems within the current simulator program. Finally, I will look at the future of simulation with specific reference to the impact of technology.

CHAPTER II

HISTORY

Simulators and simulation techniques have been employed both by military and civilian agencies for many years. Flight simulation can be traced back to the late 1800s; with the first flight trainer originating in England in 1910. That first trainer was a replica of early aircraft and was mounted on a base which allowed limited movement in pitch, roll, and yaw.(3:3)

Common to the vocabulary of all aircrews is the name "Link." Link simulators have been "flown" by literally millions of people. As early as 1931, the U.S. Navy purchased Link trainers for pilot training at Pensacola Naval Air Station, Florida.(3:38)

The need for "mass-producing" pilots during world War II gave simulation a real boost. Thousands of pilots were trained in the C-8 type trainer during and after the war. Both training time and training aircraft were in short supply. The conclusion was that programmed practice in the C-8 could significantly reduce the time needed and cost required for basic flying skills. One study concluded that five to seven hours of trainer time equated to approximately three hours of actual flight instruction time.(3:67)

To this point in time, training devices were characterized by a generic, open cockpit device, mounted on a pedestal for movement (pitch, yaw, bank), and having standard light aircraft instrumentation.(4:29) However, progress in analog computer technology made possible a new

generation of flight simulation. In 1949, the first trainer to simulate a jet-powered aircraft was built. This trainer was the early version of the T-4 and T-7 trainers still in use for undergraduate pilot training in the T-37 and T-38 aircraft, respectively.(3:79)

But most of the major advances in simulation technology have taken place in the last 25 years. In the sixties, the first attempts were made to develop visual simulation and sensor simulation. This period also saw the introduction of the photo-transparency approach for radar land mass simulation. Later versions of this development are still in use today. Motion systems also came into being in the late sixties. By 1970, helped by the rapid growth in digital computers, we had refined motion systems and computer-image generation capabilities.(5:14-15)

By the mid seventies, we saw the introduction of simulators where the pilot could fly an air-to-air scenario against the computer or against another pilot located in a second simulator. Additionally, simulators were introduced to teach formation flying in undergraduate pilot training and to practice weapons delivery techniques for fighter crews. All these simulators have wide fields of view (from near 110 degrees in the weapons delivery simulator to near 360 degrees in the air-to-air simulator).(4:18-23)

Today we have a whole new generation of simulation available, and the future is indeed promising.

CHAPTER III

FLIGHT SIMULATORS TODAY

Flight simulators are used widely for purposes of training and evaluation, limited at one time largely to undergraduate pilot training, their use extends now to advanced training for high performance fighter aircraft in both the air-to-air and the air-to-surface mission areas. Additionally, they are used to complement training in areas such as aerial refueling, formation flying, and procedures training. The well-known reasons for their use include lower operating costs; safety; independence of weather, air traffic, and geography; and their excellent amenability to performance measurement.

At present, the development of flight simulator training devices for the Air Force concentrates heavily on high-realism, full-mission systems. The B-52 mission crew trainer is illustrative of one weapon system's minimum requirement for a training device. It is capable of operating as a trainer for individual crew stations as well as providing a complete crew with the opportunity to improve total crew coordination by training as a unit. Its sophistication allows it to duplicate every aircraft function from start-up to shutdown.(6:54-55)

Fighter simulators, while usually configured around only a single seat, represent an even higher state of the art. At the upper end of the spectrum is possibly the McDonnell Douglas simulator center. Principally designed for use in the development of new fighter concepts, it can

simulate a complete air-to-air, multi-aircraft, combat scenario. Up to 12 aircraft can engage in air combat, and up to 32 missiles can be tracked and scored simultaneously. Surface-to-air missiles streak past the fighters, air-to-air missiles fill the sky, and "killed" fighters blow up. The entire event is monitored by instructors and is complete with such features as "freeze" and "replay." (7:17-18)

Today's flight simulators and simulator programs continue to be controversial, are plagued with problems, and are strongly supported by some while being strongly rejected by others. But, it is perfectly clear that in one form or another, flight simulators are here to stay. Current Department of Defense policy is "... to maintain or increase combat readiness to the extent possible through the use of simulation, miniaturization, and substitution." (8:23)

With the great amounts of control that the U.S. Congress can exercise over DoD budgets, it is interesting to note Georgia Congressman Newt Gingrich's views on flight simulators:

As technology collapses the time and distance of combat while expanding the complexity and capability of the systems used to fight, it becomes more and more difficult to practice to the point of proficiency with the systems and even more difficult to recreate the interaction of these systems with meaningful maneuvers. To avoid the costly mistakes of the past, and to better prepare for the inevitable high speed, high technology, real time decision-making type of warfare, it is vital that we turn to simulators. Simulation was originally developed in the military and was only later taken up by civilians, mostly airlines, who are primary users today. Among the three major services the U.S. Army retains its historic lead in the use of simulation. The Army's intensive use of simulators, particularly at Ft. Rucker with the development of helicopter training programs, is a major

breakthrough. The objective of simulation is to elevate the competence of the trainee -- not just familiarize him with the system, but also to enable him to dominate it. We have focused too long on the hardware element in our security equation, ignoring the vital element that only capable people make the equipment work effectively. Simulation gives us the means to achieve the goal of operational preeminence over our enemies.(8:29)

Advantages

The effective use of simulators gains its maximum advantage in training by demonstrations which are impossible, or at least unacceptably expensive to demonstrate in an actual aircraft or other weapon system. Thus, for example, flight simulators are used to teach emergency procedures, flight through dangerously bad weather, devastating enemy attacks, very low-level and high-speed flight and other potentially hazardous conditions without risking aircraft, lives or property.

Among the many other advantages of simulators is their ability to substitute simulated for actual firing of missiles and other armaments. Very large cost savings in both missiles and targets are achieved through simulations.

Simulators can be effectively used for tactics development. Air Combat Maneuvering (ACM) simulators form a unique complement to aircraft flight testing. Aircrews can assess methods for defeating enemy-fired missiles and then train using these concepts. Since it is impossible to visually simulate a deployed missile in an operational environment, the tactics development and subsequent training of this task are best handled in ACM simulators.(9:11-12)

Simulators can provide many economics. They are great energy savers since the fuel used in the aircraft and all support functions (maintenance vehicles, fuel trucks, starting units, etc.) is saved. Safety advantages are obvious. Simulators can't crash into one another or into the ground. Their armaments can't explode because of defects, hangfires, and the like (unless you want them to!). The extensive costs of manpower and materials needed to keep the actual equipment up for safe and effective training are real factors as well.

With respect to operating cost, the Institute for Defense Analyses (IDA) published a study just two years ago concluding that:

1. The average variable operating costs of 39 simulators in operation in the FY 1980-1981 time period fall within a narrow range (\$116 to \$170 per operating hour), despite the diversity of simulator type and associated aircraft missions (e.g., bomber, fighter, cargo), sizes, or types (i.e., fixed-wing or rotary-wing).
2. The median ratio of the 39 military simulator-to-aircraft operating costs is eight percent in FY 1980-1981.
3. The simulator-to-aircraft operating costs ratios in the FY 1975-1976 and FY 1980-1981 time periods are essentially the same.(10:4-15)

All of these important considerations are worthwhile, but none are as important as the realistic training that can be provided by simulators. For example, Space Shuttle astronauts Truly, Engle, Young, and Crippen experienced nothing new when they completed their first two history-making flights in 1981. The only difference between the actual flight and their shuttle simulation, noted the

astronauts, was a longitudinal vibration that was less than expected. That minor discrepancy was quickly corrected on the simulator.(11:24-25)

While the Space Shuttle simulator may be a special case, other examples are readily available. A 1981 study by the USAF Human Resources Laboratory compared a "control" group of A-10 pilots who had been through simulator training, with one which had not. The simulator pilots scored dramatically better on all fronts, an advantage they retained through all phases of A-10 training.(12:13)

Motion and Visual Systems

The current U.S. Air Force position was stated in a Tactical Air Command message, dated 20 May 1982, indicating the decision "to pursue acquisition of current state-of-the-art limited-field-of-view visual systems for A-10, F-15, and F-16 simulators."(13:72) The Air Force defines a limited-field-of-view as anything less than a full 360 degree continuous visual image. The decision was reinforced in July 1984 at the completion of an Air Force evaluation of limited-field-of-view visual system training effectiveness. The evaluation concluded that the visual system was capable of substantially enhancing training and that limited-field-of-view visual systems would continue for fighter training in simulators.(14:87-91)

This decision was an economical one in that full visual systems were deemed too expensive for the relatively small amount of gain in realism and training effectiveness.

Controversy has surrounded motion ever since its introduction. In 1968, Air Force Systems Command studied the presence versus the absence of motion for simulators and concluded that the Air Force should not purchase sophisticated flight trainers unless they had adequate motion systems.(15:8)

In the 1970s, some simulators had really sophisticated motion systems. The Simulator for Air-to-Air Combat, mentioned earlier in this paper, was mounted on six-post hydraulic, synergistic motion bases.(5:18) Motion was hotly debated throughout industry, not knowing where the users were headed. But the answer to the motion or no motion question was found in visual systems and the creation of other motion cues such as g-suits and g-seats.

The visual display is now the dominant element in any simulator system and full motion functions are beginning to disappear as their cost is displaced by the visual system. Pilots have discovered that a good visual system, combined with the motion cues of g-suits and g-seats, make it virtually impossible to tell when the motion is, or is not operative.(13:74-75)

In a recent vanguard analysis performed by the Air Force, visual systems were established clearly as the number one priority for future development. Interestingly, some of the most advanced simulators, such as General Electric's

F-5E system for Thailand, delete motion entirely based on the perception that acceleration cues through g-suits and g-seats are more useful; but their visual systems are the most advanced available for their cost.(6:56)

Problems and Issues

The Air Force faces a number of problems, whose continuing nature and increasing effect tend to further emphasize the need for cost effective training devices. These problems include: the increasing complexity of weapons and other equipment; increasing enemy capabilities, non-technical trainees; increasing dependency on automatic and computer controlled devices; and rising costs. High fuel costs have been of sufficient importance to interest Congress in backing an accelerated acquisition program for flight simulators for the military.(16:15)

The 1982 Defense Science Board (DSB) Summer Study on Training and Training Technology had some interesting findings. In their report to the Secretary of Defense, the following problems pertaining specifically to simulators were identified:

1. Many training devices and simulators are over designed and over engineered. They are required to meet standards and specifications intended more for field and combat conditions than for the instructional environment in which they will be used. Substantial time and money can be saved by eliminating excessive design/manufacturing requirements.
2. A chronic complaint from the training and user community alike is that training packages/devices arrive too late for effective use, often months or even years after the weapon system has been fielded.(17:8)

Overspecification has been, and continues to be, a problem in the acquisition process. This is true despite high level emphasis on readiness and sustainability. The extra "bells and whistles" push cost and schedule to the right. With respect to specifications, program baselining and discipline are a must.

Air Force Regulation 50-11 states that we will field simulators concurrently with the aircraft. Air Force Regulation 57-4 states that simulator mods will be accomplished simultaneously with aircraft mods. Despite improvements in this area, simulators continue to be late-to-need and modifications are either late or not made at all. The following examples were briefed to the Air Force Council during the annual Simulator Program Review in 1984:

1. A-10 -- Tried to build the simulator with full tactical visual system. When the visual system became too tough and expensive (\$500m) to build, the Air Force salvaged a "cockpit trainer" two to three years late-to-need.
2. F-16 -- Tried building block approach (cockpit, radar, EW, visual). This approach resulted in the basic simulator two to three years late-to-need and safety of flight updates two to four years lagging.
3. KC-10 -- Turned to industry for a training program. The result was an on-time product because industry had an existing DC-10 program with simulators and instructors.(18:11-12)

It is interesting to note that the Strategic Air Command is in fact buying three KC-10 simulators, the first of which became operational in February of this year.(19:68)

Negative training is a direct impact of simulators being late-to-need and late-to-mod. It is not unusual for

an aircrew to "fly" the simulator having to make allowances for differences between it and the aircraft sitting on the ramp. Differences typically include switches in different cockpit locations, different types of gauges (i.e., dial versus digital), and the absence of newly added equipment.

Another problem has haunted the flight simulation equation since the beginning. That problem has to do with pilot/aircrew acceptance. Simulators have often been viewed as a threat to flying time and sorties. Aircrew experiences with inferior simulators, simulators not in good repair, and simulators late-to-need don't help the cause for simulation at all. The type of opposition I am referring to was typified in a 1974 Air War College paper, later published in the Air University Review, which concluded that increased simulation would result in "... a potentially serious dilution of airpower" and that simulation was "... a peril to tactical airpower." (2:1,6)

CHAPTER IV

THE FUTURE

While the simulation of aircraft characteristics has taken place for more than 50 years, it was not until the advent of computers that they reached their present sophistication. Technological advances in computers, electronics, and visual systems have made it possible to virtually duplicate an aircraft's performance and that of its weapon systems through sight, sound, and feel. And the growth in computer science is passing on the type of economics seen in pocket calculators. In all likelihood, the technology revolution will continue its self-sustaining momentum into the foreseeable future.

Key developments contributing to improved simulation and simulation effectiveness in the near future fall into three primary areas: visual technology; distributed processing techniques; and artificial intelligence technology.

The simulation of visual information is the most rapidly advancing area of flight simulation, and with good reason. The human visual sense is by far the most rich in information. There are more cues available from the visual sense than from taste, smell, hearing or touch. At the same time, the military requirement for advanced visual systems grows stronger. Needs include better resolution for air-to-air type scenarios and the effective simulation of low-level nap-of-the earth missions. And just down the road in visuals is holography, the science of producing

three-dimensional images through the use of lasers.

General Electric, for example, is concentrating on improving resolution without reducing the field of view. This has been a fundamental limitation of most image presentation. Through the use of very large-scale integration, General Electric expects to shrink the system, resulting in reduced costs and increased training capabilities. Initial work in this area will be seen in visual imagery for West Germany's Panavia Tornado strike-reconnaissance aircraft simulators.(20:239)

Link, the household name in flight simulators, is concentrating on visual and software development. The company is moving toward application of distributed microprocessor technology to the overall simulator, not just the visual portion of the system.

A major problem with increasing the visual field-of-view is resolution. One way to overcome this problem is to concentrate on the fine detail in the area of interest. Hin-Man Tong, Link's director for visual systems reports that:

Link is developing a new visual system that provides an area of high-resolution imagery, covering about 20 degrees, that moves to wherever the subject's eyes are directed within the overall visual scene.(20:243)

The next generation of simulators will undoubtedly feature the integration of more "smartness" through the arrival of artificial intelligence. An example of the use of artificial intelligence would be in performing emergency procedures. If the trainee deals with a certain emergency

very well, the computer might make the problem even more difficult. On the other hand, if the trainee has difficulty with the emergency, the computer would not compound the problem. This can be applied across the spectrum of training in the simulator. The computer will continuously rate the trainee's performance and adjust the scenario in order to optimize the learning. Taken to the next logical step, the computer could manage individual training by adapting future training based upon the "remembered" past performances.(21:78-81)

Soon, the "flight" simulator will be joined by the "in-flight" simulator. This is possible by "hard-wiring" the real aircraft such that the cockpit can be turned into a simulator. For example, the simulation could present the pilot with the appearance of attacking enemy aircraft or other emergency procedures. Through pure simulation, the problems would have to be dealt with in the world of actual flight.(19:68)

To deal with the impact of technology on flight simulation, the Air Force appears to be ready. The recently published Program Management Directive for Advanced Simulator Technology states that:

Advanced Simulator Technology is a continuing program to improve Air Force capabilities through the design, development, and fabrication of prototype simulation systems that lead to improved, cost-effective flight training simulators.

The objective of this program is ... to provide advanced and enhanced visual system capabilities in the 1990s ... to select the most promising simulation technology for continued development into demonstrable simulator subsystems ... recognizing that simulator training can act as a force multiplier.(22:1-3)

CHAPTER V

CONCLUSIONS

Given the evidence, I don't believe there is any doubt that flight simulators are here to stay. But their very existence provokes a couple of questions. The first question that might come to mind is, Are simulators needed? I believe that the answer is, emphatically, yes. The second question, which is far more important and relevant, is, How sophisticated should they be?

Today we still try to build a simulator that does everything the aircraft can. This was our goal in the 1970s when we tried to replace hands-on flying time with simulator flying time. Unfortunately, the excitement of simulation and rapid advances in technology have continued until industry can produce far more simulator than the Air Force can afford.

I believe that the Air Force (all the Services for that matter) should make a concentrated effort to match the simulator to the task(s) being trained and not buy the highest capability simulator industry has to offer. We need to separate safety-of-flight type training. Simulators for warfighting task training should do just that, and nothing more. The Tactical Air Forces (TAF) decision for limited-field-of-view visual systems for F-15, F-16, and A-10 simulators is a step in the right direction. The ideal flight simulator would enable a pilot or aircrew to debut in combat feeling they had been there before. But, in my mind, the objective of a flight simulator is to provide sufficient

capability for realistic training at an affordable cost.

Something must be done to correct the problems of simulators arriving late-to-need and modifications lagging. It is very important that aircrews have simulators when they are needed (i.e., fielded along with the aircraft) and that the simulator be as current as the aircraft (i.e., modified whenever the aircraft is). Correcting these problems would go a long way toward aircrew acceptance of simulators as well as improving training capabilities.

The ultimate goal is increased combat capability through training. As Admiral Isaac C. Kidd, Jr. (USN Retired), Chairman of the 1982 DSB Summer Study on Training and Technology noted:

Training is the force multiplier most critical to our combat capabilities that can now give us a very large return in relatively shorter time than it takes to introduce new systems. It is, in fact, one of the soundest ways to get the fastest positive returns from so many of the weapon systems and manpower investments we have already made.(23:7)

I believe that flight simulators should continue to complement Air Force flying hour programs. Simulation can add an extra dimension of realism to operational training. Simulators don't substitute for flying hours, but they make the actual hours flown count more. Simulators have the potential, especially with rapid technological advances, to yield even greater benefits as our training requirement becomes more complex. The bottom line is that everyone stands to lose if aircrews are not given the very best training that technology has to offer.

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